Beam-beam simulations with beamstrahlung for FCC-ee

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Outline

→ Dynamic effects: Analytical estimations / simulations

→ Beam-beam simulations with beamstrahlung in SAD

1) @ 182.5 GeV
2) @ 45.6 GeV

→ Conclusions and perspectives

Dynamic Effects -I

→**Dynamic effects:** Change of the Twiss parameters due to the beam-beam quadrupolar focusing

→ These effects are enhanced by running at half or full integer resonances

→Two dynamic effects: dynamic beta and dynamic emittance

→ Dynamic beta:

$$\begin{pmatrix} \cos\mu & \beta\sin\mu \\ -\frac{1}{\beta}\sin\mu & \cos\mu \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -\frac{1}{2f} & 1 \end{pmatrix} \begin{pmatrix} \cos\mu_0 & \beta_0\sin\mu_0 \\ -\frac{1}{\beta_0}\sin\mu_0 & \cos\mu_0 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2f} & 1 \end{pmatrix}$$

- **The beam-beam parameter** $\xi_{x,y} = \frac{\beta_{0(x,y)}}{4\pi f_{x,y}}$
- $\frac{1}{f_{x,y}}$ **is the beam-beam interaction strength**
- $\beta_{x,y} = \frac{\beta_{0(x,y)}}{\sqrt{1-(2\pi\xi_{x,y})^2+4\pi\xi_{x,y}\cot(\mu_{0(x,y)})}}$ **; where** $\mu_{0(x,y)} = 2\pi\nu_{0(x,y)}$

Dynamic Effects -II

→ Analytical estimations predict :

- 50% reduction in β_x and 44% reduction in β_y @ Top energies
- 34% reduction in β_y @ Z energy

→ Above estimations were confirmed by a thin quadrupole insertion at both IPs in both lattices

→ Vertical misalignments of sextupoles were introduced to create the x-y coupling overall the ring

→ Dynamic emittance [1] could also be predicted in presence of radiation and vertical emittance

→ Predictions: 38% enhancement of ϵ_x and 43% enhancement of ϵ_y @ Top

[1] "Self-consistent b functions and emittances of round colliding beams", A. V. Otboyev and E. A. Perevedentsev, PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME 2, 104401

Beamstrahlung simulations I

→ Weak strong beam-beam simulations were performed by the SAD [2] version of BBWS [3]
→ Beam-beam elements were inserted at both IPs with beamstrahlung flag ON
→ The crossing angle is simulated, the crab waist is employed for the weak beam
→ The Strong beam is not crab waisted

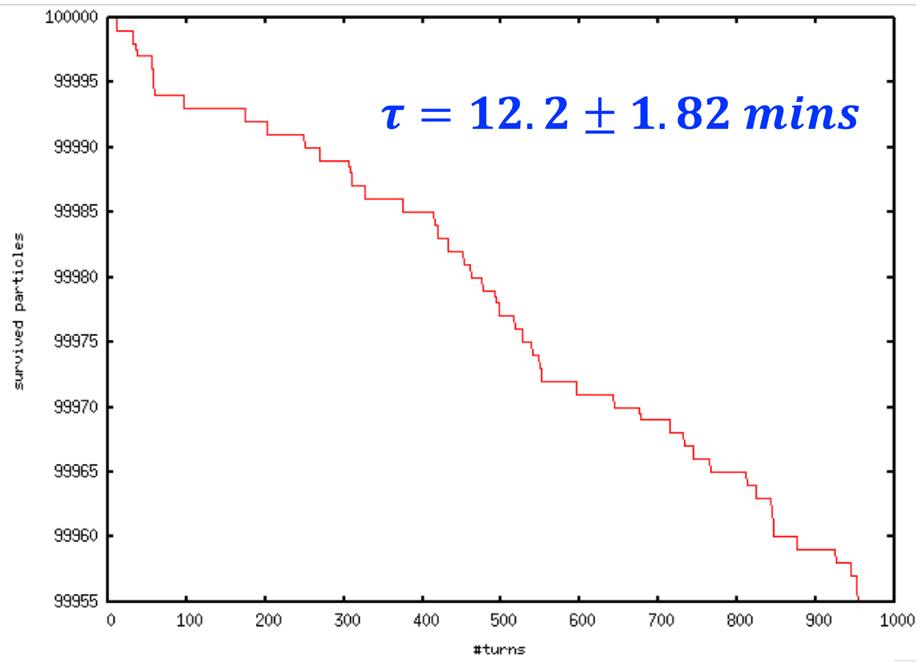
@ 182.5 GeV: (first lattice version)
→ Weak beam population $N_p = 10^5$

→Physical apertures are inserted including synchrotron masks in the interaction region

→ Vertical misalignments of sextupoles

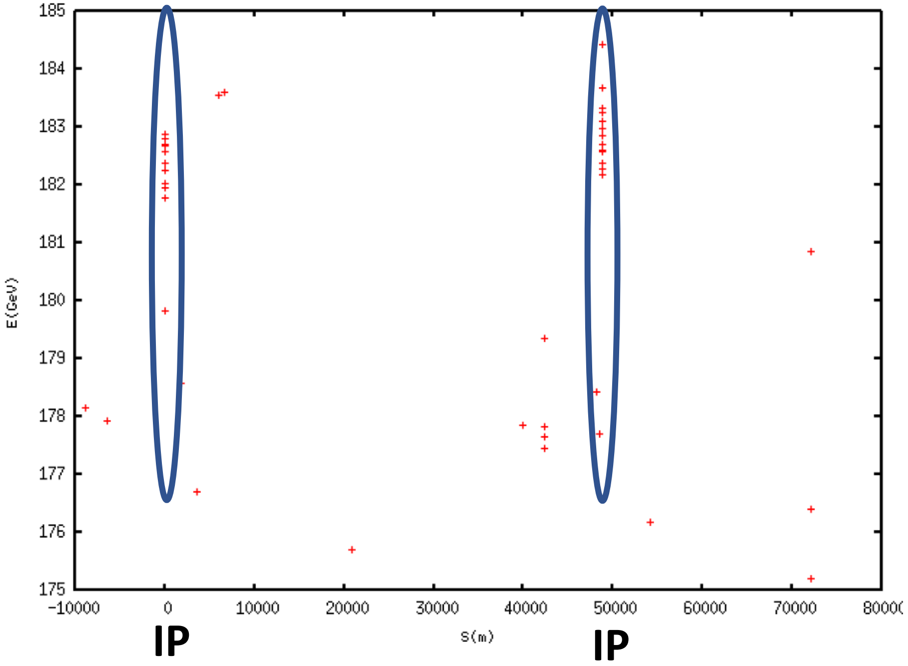
→ Tracking over 1000 turns

→ Update strong beam parameters every one damping period (50 turns)

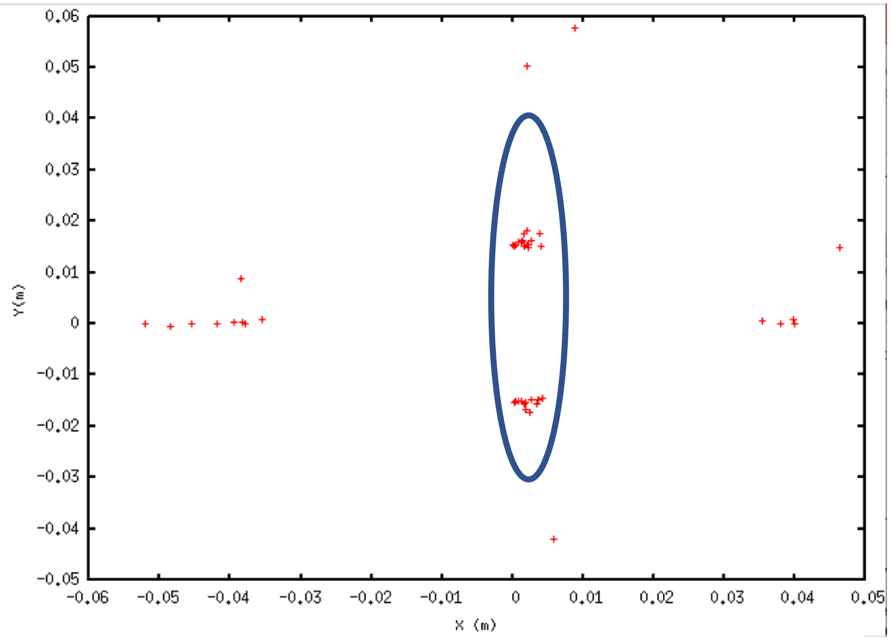


[2] http://acc-physics.kek.jp/SAD/SADHelp.html
[3] K. Ohmi, "Beam-Beam Effects in CEPC and TLEP," Proc. HF2014, Beijing (2014).

Beamstrahlung simulations II



Energy of lost particles as a function of their loss position in the ring



Transverse amplitudes of the lost particles

→Loss map was constructed (need higher statistics)

→Losses are mainly concentrated around the IP ($\pm\, 5\ m$) in the vertical plane

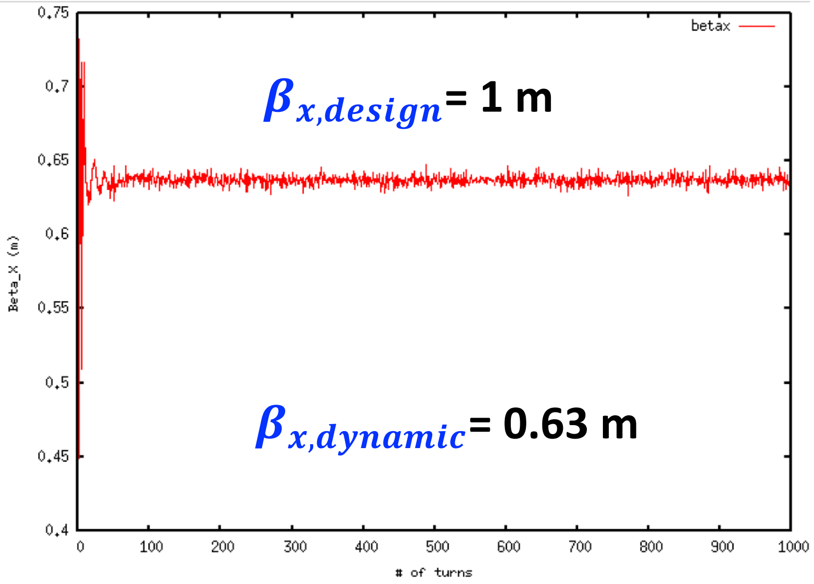
→Collimators are needed to protect the IR from the above losses

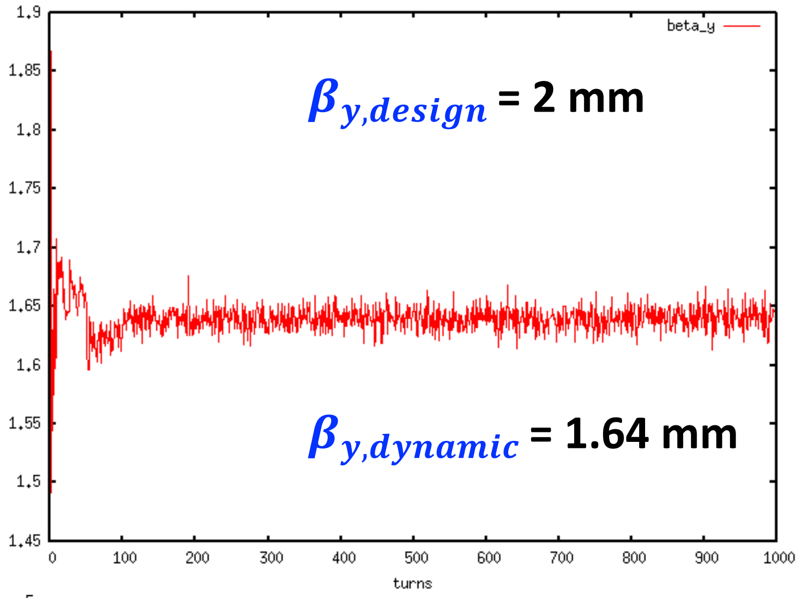
Dynamic Beta/Emittance

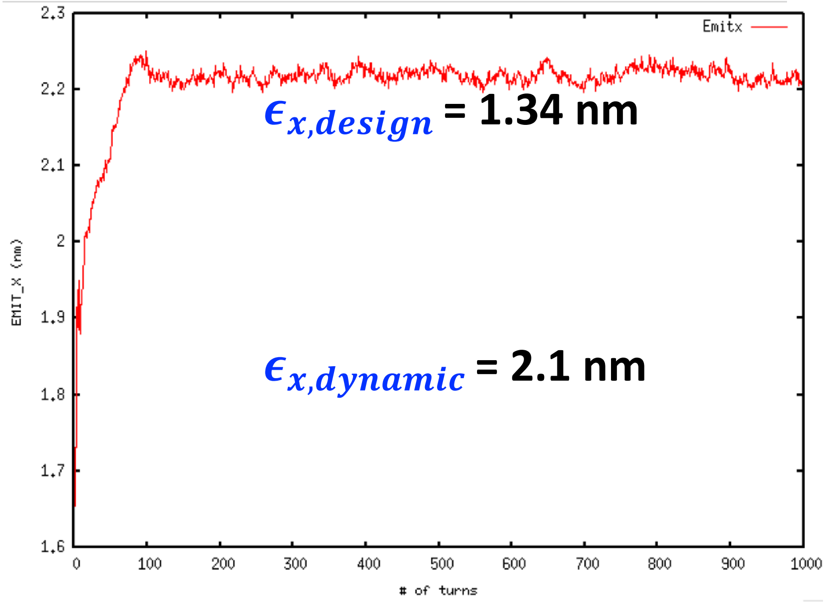
→ Dynamic effects could be observed in the non-linear beam-beam simulations

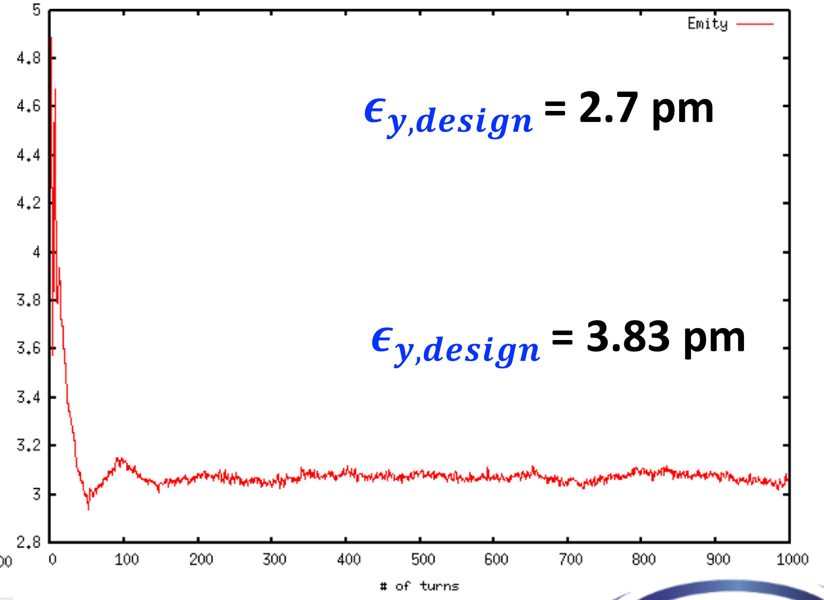
→ Results are different from linear beam-beam simulations

→ How do these results appear without beam-beam element insertion??









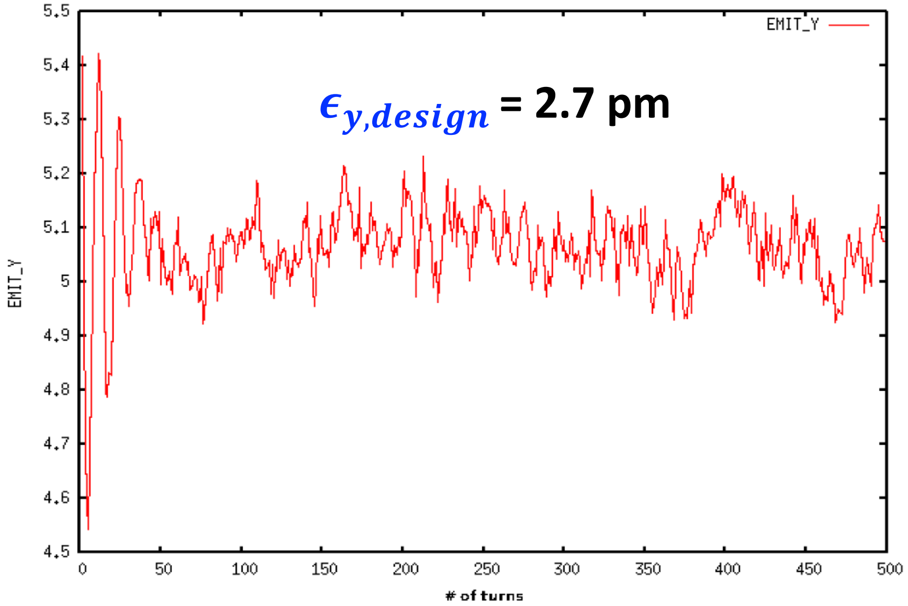
No beam-beam

→ Remove the beam beam element and track in the lattice in the presence of sextupole misalignments

→ Vertical emittance is now almost twice the design value

→ Reason: Residual coupling/dispersion at FRF & IP due to sextupole misalignments

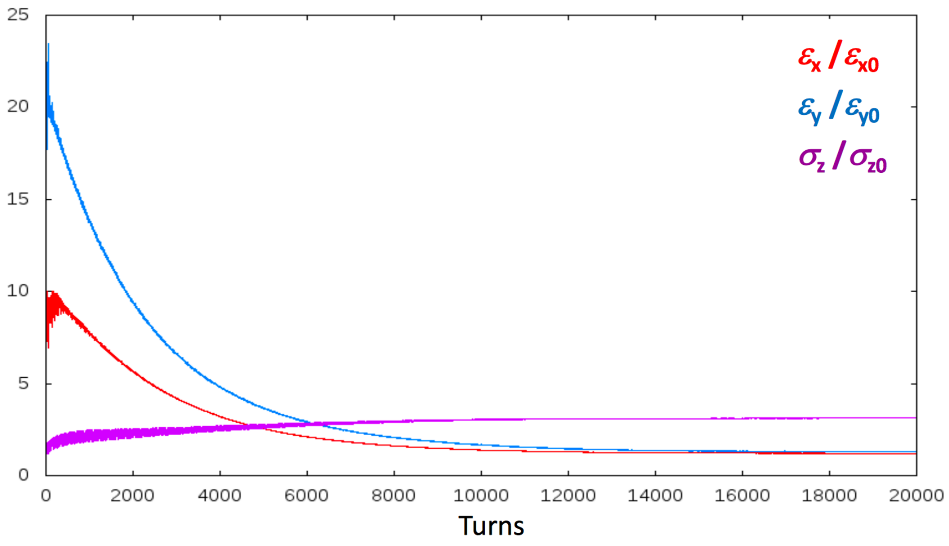
→ Correction of residual coupling/dispersion is needed

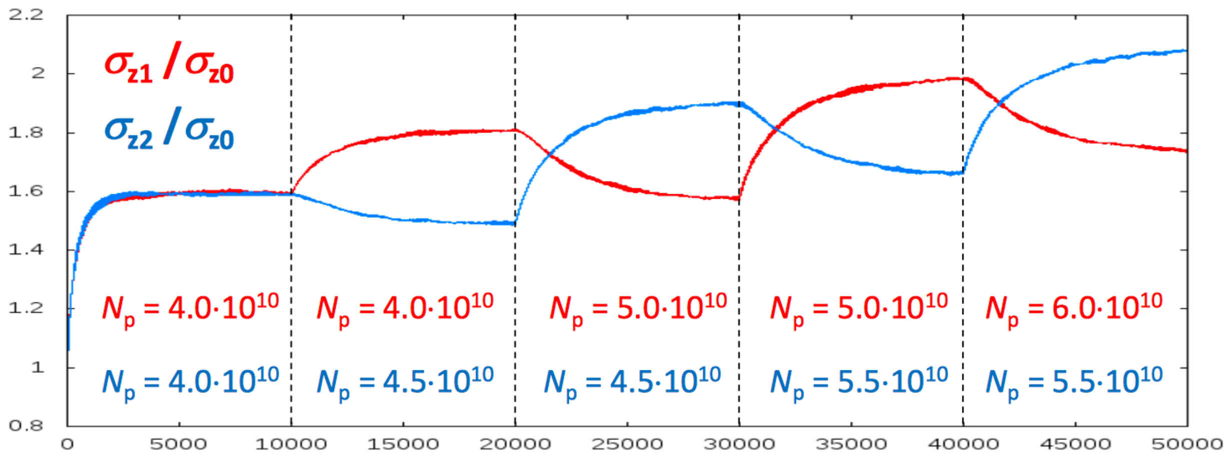


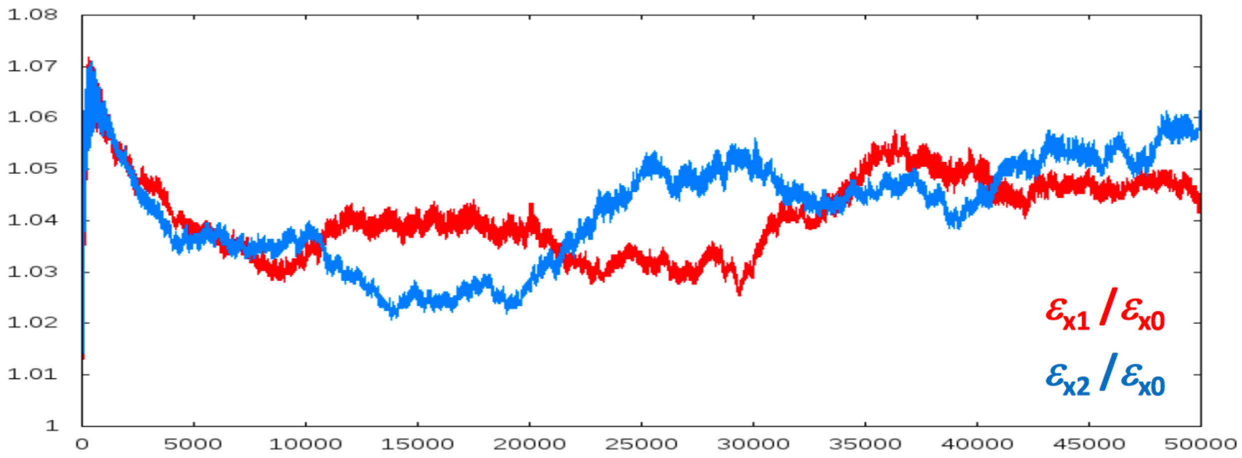
Beamstrahlung at Z (I)

D. Shatilov

Bootstrapping







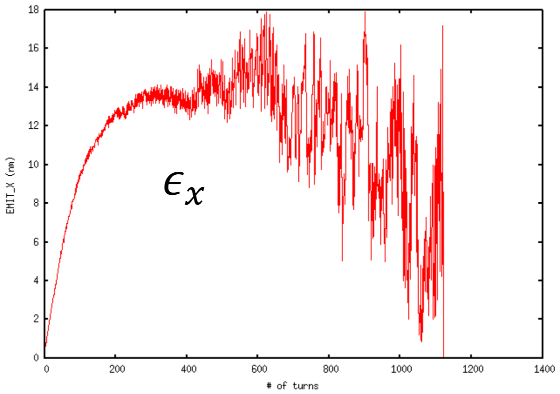
→Due to strong beam-beam at Z, beam sizes at the IP will blow up

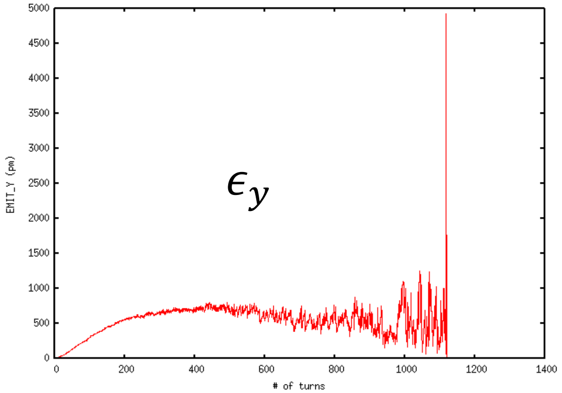
→ Bootstrapping will be considered where injection will be done on stages

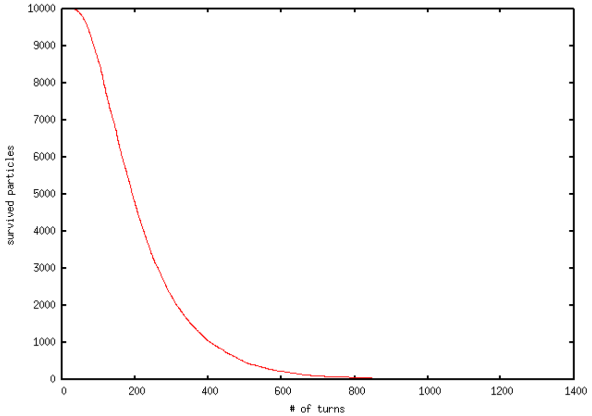
Beamstrahlung at Z (II)

→ Represent the bootstrapping by simulating beam parameters after beamstrahlung and bootstrapping

→ 20 slices : Large beam-beam effect → large emittance blow-up → Beam loss



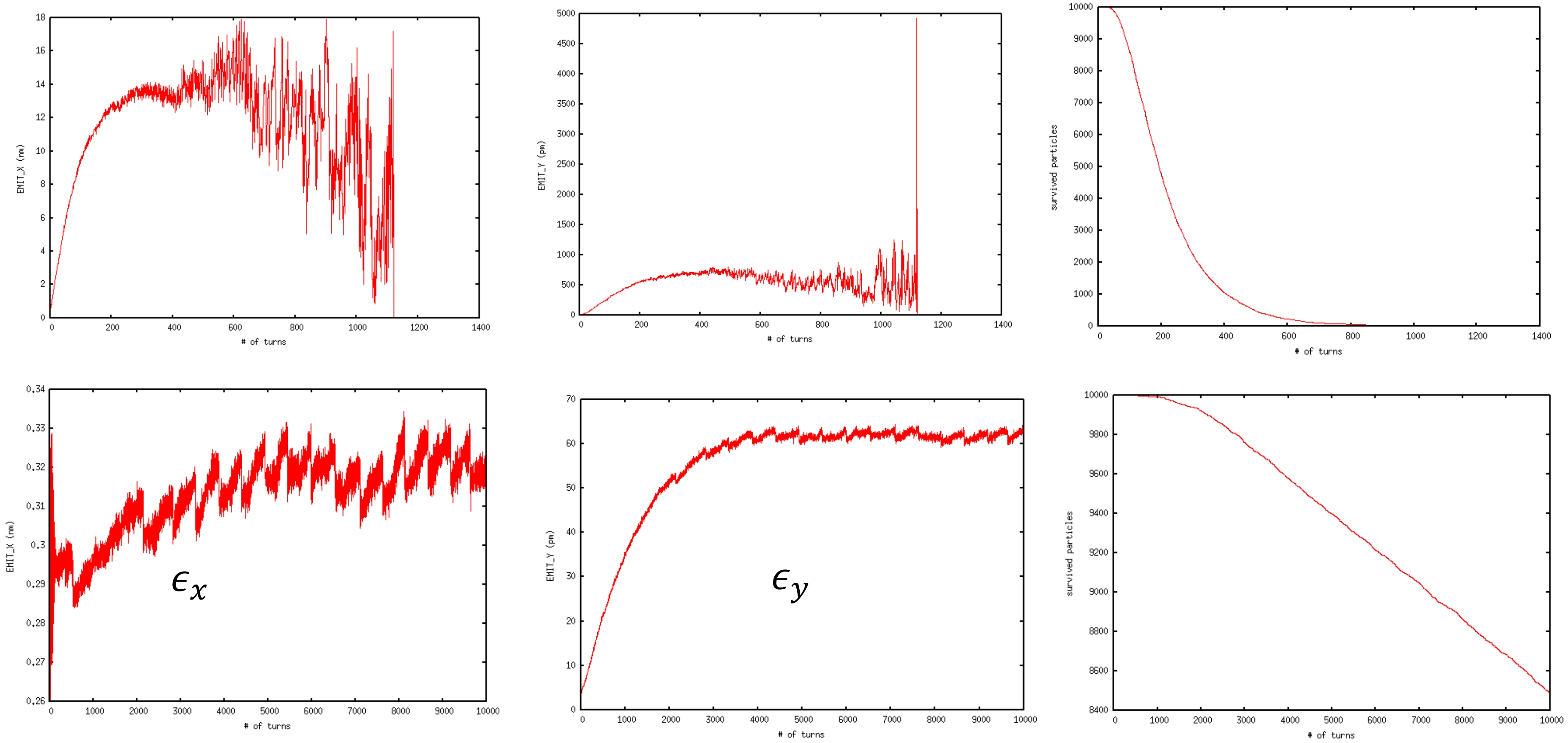




→ The bunch length is around 30 times larger than the interaction region

→ Number of slices should be high to correctly represent the beam-beam interaction

Beamstrahlung at Z (III)



20 slices

500 slices

- → Slicing of the strong beam has a big effect on the blowup
- → But the blowup is still large and causing a large beam loss
- → Is it again the residual dispersions and xy couplings ?

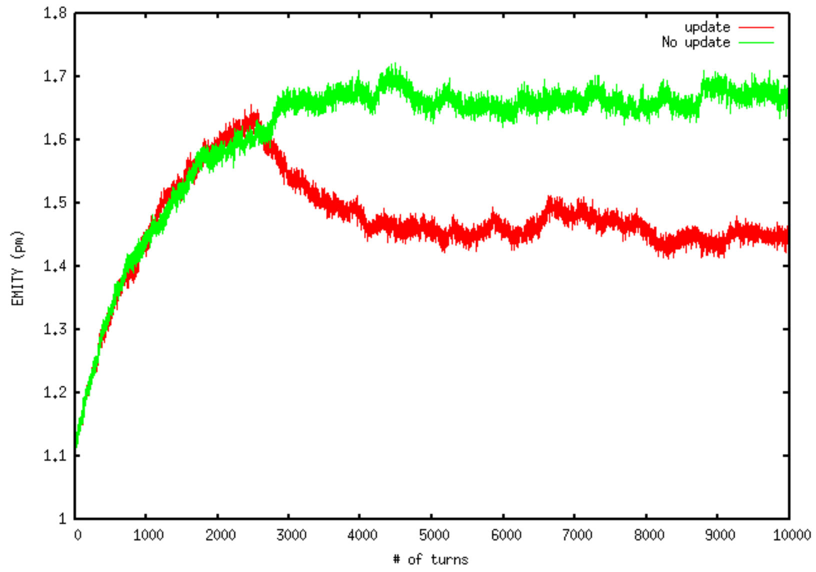
No misalignments

→ Remove the vertical sextupole misalignments and instead do artificial excitation/damping of the weak beam

→ Blow-up decreases significantly and no beam losses over 10000 turns

→ The blow-up thus is not due to the beam-beam itself but due to the residual dispersions and x-y coupling resulting from the vertical sextupole mislignments

→ The residuals are higher at Z due to the higher x-y coupling (Higher RMS of sextupole misalignments)



Correction Methods

→ Local corrections were considered for our studies (IP and FRF)

→ **Two methods are currently being considered:**

1) Optimize the skew quadrupole components of the 2N sextupoles upstream/downstream of the to-be-corrected location to suppress dispersions/couplings at the latter

2) Set randomly the skew quadrupole and skew sextupole components of all the sextupoles to create the needed xy coupling and to guarantee a negligible dispersion/coupling at the IPs and FRF

3) Not to forget the anomalous equilibrium emittance due to the residuals of chromaticity corrections [4]

→Work is currently in progress

→ Error and correction studies overall the ring were carried by S. Aumon (Presentations by T. Tydecks and T. Charles)

[4]"Anomalous equilibrium emittance due to chromaticity in electron storage rings", Katsunobu Oide and Haruyo Koiso, Physical review E, VOLUME 49, NUMBER 5

Conclusions

→ Dynamic effects has been analytically estimated and cross checked with a thin quadrupole insertion at both IPs for Top and Z energies

→ Beamstrahlung lifetime and loss map were simulated with a multi-turn tracking simulation

→ Losses were mainly concentrated in the IR at $\pm 5\ m$ from the IP

→ Collimators are necessary to protect the IR from losses from Beamstrahlung

→ Residual dispersions/x-y couplings due to vertical sextupole misalignments create a vertical emittance blow-up at IP that need to be corrected

Perspectives

→ Analytical calculations of the dynamic horizontal emittance using [1] to compare to simulations

→ Further continuation of the correction studies for the residual dispersion/coupling

→ After understanding the above, go for collimation studies (position, aperture and material)

→ With Ohmi san, try to do some beam-beam studies during the SuperKEKB commissioning in the next few months if possible

Thank you for your attention